



From Cocktail Napkin to Concept Feasibility

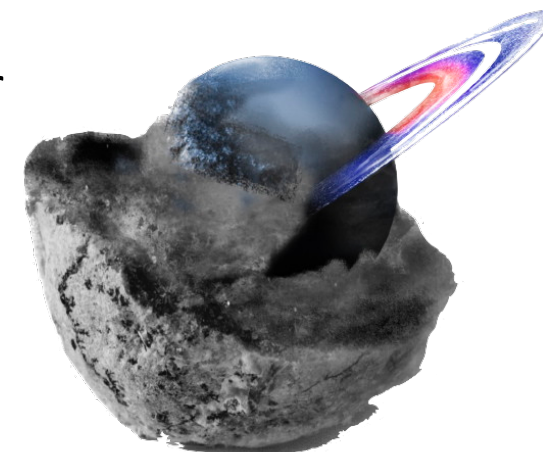
Spacecraft Design in Early Formulation with TATER

Presented by Kristina Hogstrom

Co-authors:

Jonathan Murphy, Steven Zusack, Andrew Coffey, Chester Borden,
Alan Didion, Damon Landau, Adam Nelessen, Macon Vining, & Robert Miller

Jet Propulsion Laboratory, Pasadena, CA



Concept Feasibility and the A-Team

*From cocktail
napkin*



*To ideas on
post-its*



**Multi
-vote**

*To "crowd
favorites"*



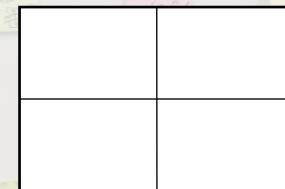
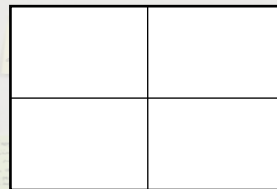
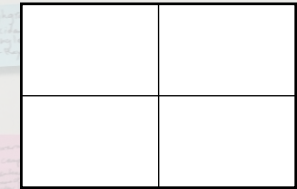
Cost

**Technical
Feasibility**

**Science
Value**

Risk

*To concepts on
quad charts*

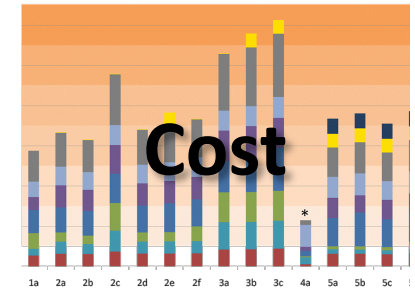
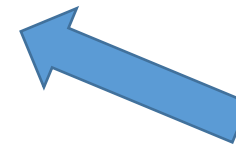
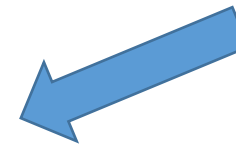
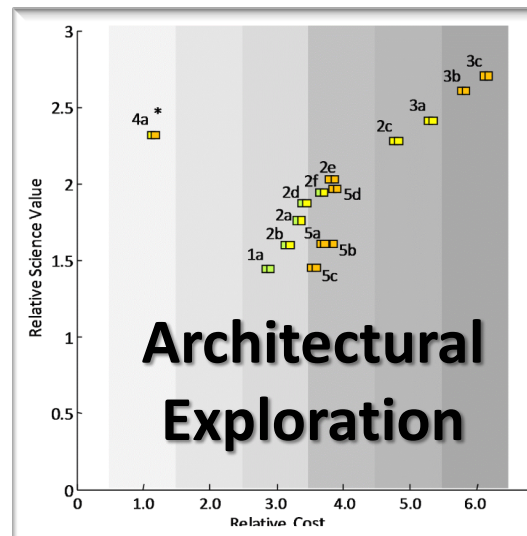
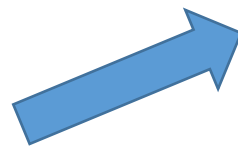
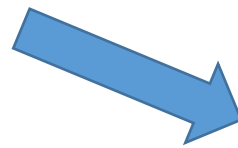
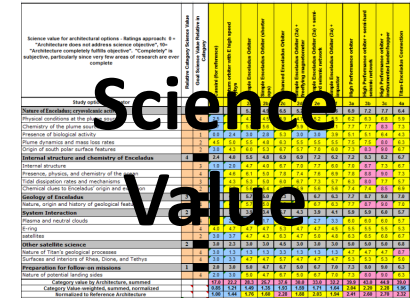
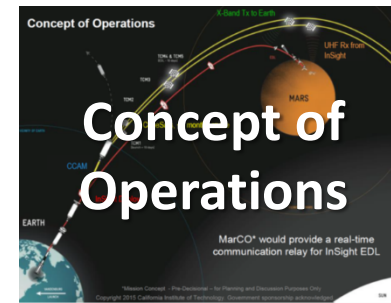
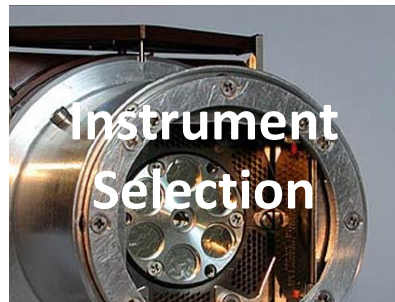


***Need to quantify figures of merit early in the formulation process to
select most promising concepts***

The Toolbox for Architectural Tradespace Exploration and Refinement



TATER covers all of the driving factors needed to describe and compare concepts



| Mission Risk Architecture Ranking | | | | Implementation Risk Architecture Ranking | | | |
|-----------------------------------|-----|--------|-------|--|-----|--------|-------|
| Arch | Red | Yellow | Green | Arch | Red | Yellow | Green |
| 2e | 0 | 4 | 12 | 5a | 0 | 5 | 6 |
| 3b | 0 | 4 | 12 | 5d | 0 | 5 | 6 |
| 3c | 0 | 4 | 12 | 5b | 0 | 4 | 6 |
| 5a | 0 | 3 | 9 | 3c | 0 | 4 | 4 |
| 5d | 0 | 3 | 9 | 5b | 0 | 4 | 2 |
| 5b | 0 | 3 | 9 | 2e | 0 | 2 | 8 |
| 5c | 0 | 3 | 9 | 2c | 0 | 2 | 7 |
| 4a | 0 | 2 | 8 | 3a | 0 | 1 | 10 |
| 2c | 0 | 2 | 7 | 2d | 0 | 1 | 9 |
| 3a | 0 | 2 | 7 | 2f | 0 | 1 | 8 |
| 2d | 0 | 1 | 10 | 2a | 0 | 1 | 8 |
| 2f | 0 | 1 | 9 | 2b | 0 | 1 | 8 |
| 2a | 0 | 1 | 8 | 1a | 0 | 1 | 5 |
| 1a | 0 | 1 | 5 | | | | |

Reduction in Mission Return/Consumption of Margin

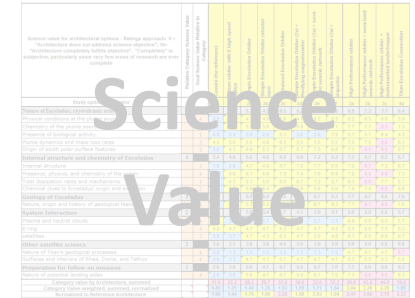
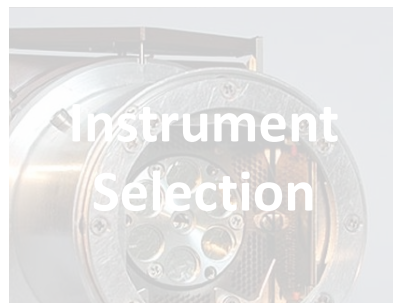
- Mission failure/Overrun
- Significant
- Moderate
- Small to moderate
- Minimal



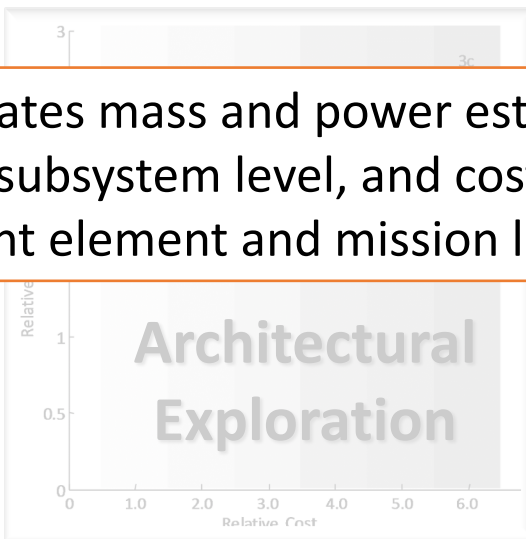
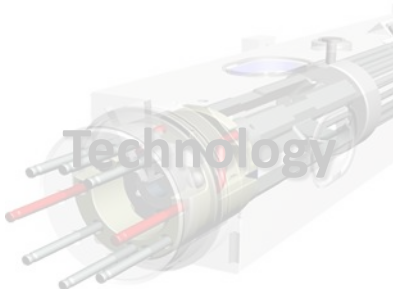
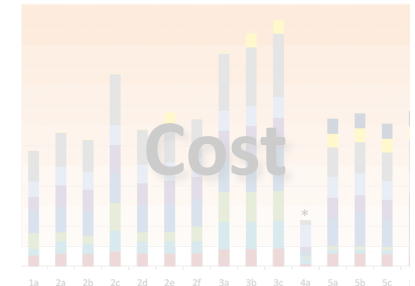
The Toolbox for Architectural Tradespace Exploration and Refinement



TATER covers all of the driving factors needed to describe and compare concepts



Generates mass and power estimates at the subsystem level, and cost at the flight element and mission level



| Mission Risk Architecture Ranking | | | | | Implementation Risk Architecture Ranking | | | | |
|-----------------------------------|-----|--------|-------|--|--|-----|--------|-------|--|
| Arch | Red | Yellow | Green | | Arch | Red | Yellow | Green | |
| 2e | 0 | 4 | 12 | | 5a | 0 | 5 | 6 | |
| 3b | 0 | 4 | 12 | | 5d | 0 | 5 | 6 | |
| 3c | 0 | 4 | 12 | | 5b | 0 | 4 | 6 | |
| 5a | 0 | 3 | | | 3c | 0 | 4 | 4 | |
| 5d | 0 | 3 | | | | 0 | 4 | 2 | |
| 5b | 0 | 3 | | | | | | | |
| 5c | 0 | 3 | | | | | | | |
| 4a | 0 | 2 | 8 | | 2e | 0 | 5 | 6 | |
| 2c | 0 | 2 | 7 | | 2c | 0 | 5 | 6 | |
| 3a | 0 | 2 | 7 | | 3a | 0 | 5 | 6 | |
| 3d | 0 | 2 | 7 | | 2d | 0 | 5 | 6 | |
| 2f | 0 | 1 | 10 | | 2f | 0 | 5 | 6 | |
| 2a | 0 | 1 | 8 | | 2a | 0 | 5 | 6 | |
| 2b | 0 | 1 | 8 | | 2b | 0 | 5 | 6 | |
| 1a | 0 | 1 | 5 | | 1a | 0 | 5 | 6 | |

Reduction in Mission Return/Consumption of Margin

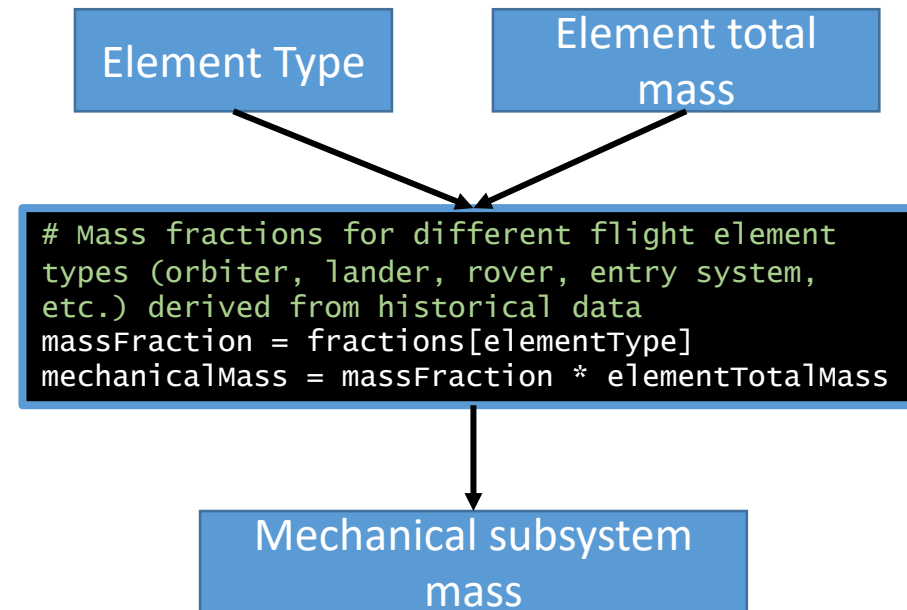
- Mission failure/Overrun
- Significant
- Moderate
- Small to moderate
- Minimal



The TATER Spacecraft Design Model

TATER is a collection of subsystem-level and component-level models, based on physics or regressed from historical data

Model that estimates the mechanical subsystem mass as a fraction of the total flight element mass

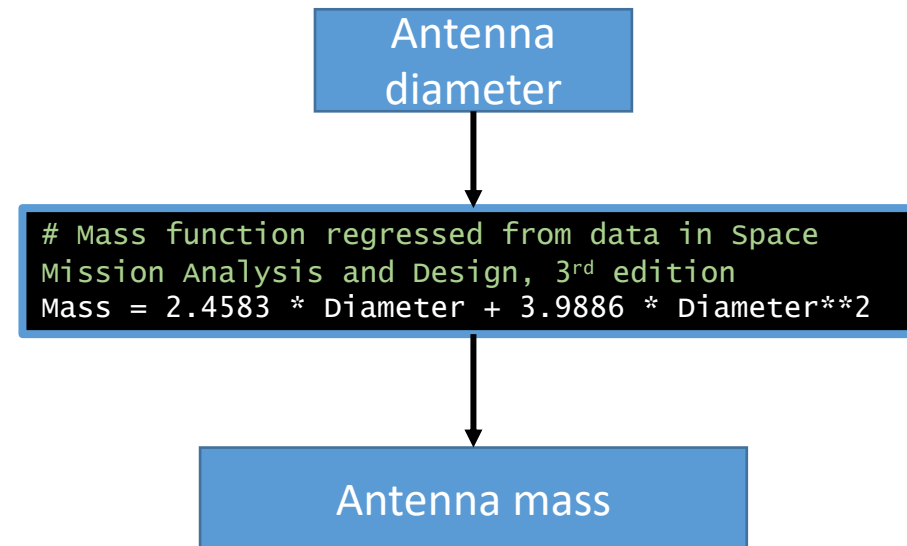




The TATER Spacecraft Design Model

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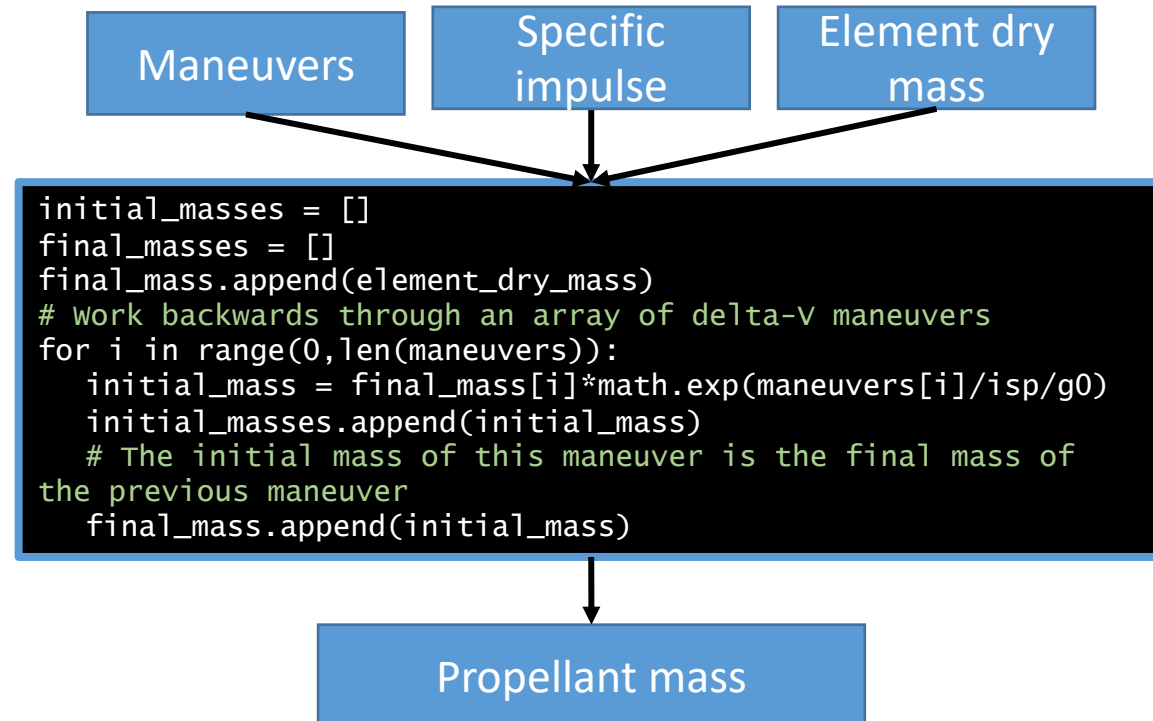
Model that estimates the antenna mass as a function of its diameter



The TATER Spacecraft Design Model

TATER is a collection of subsystem-level and component-level models, based on physics or regressed from historical data

Model that computes the total propellant for a given propulsion system based on a table of delta-V maneuvers and other mass-changing events





TATER in the Integrated Modeling Environment

Add data blocks
with
recognizable tags
called aspects

Nest data blocks
to create tree
structure

The screenshot shows a web browser window with the address bar displaying `https://diecast.jpl.nasa.gov/app.html?studyId=study_513508805493&workspace=root`. The application title is "Demo - IME Workspace". The main interface has a blue header bar with the word "Demo" on the left and "all studies" with a user icon on the right. Below the header, the main workspace area is labeled "root" and contains a clipboard icon and a refresh icon. On the right side, there is a sidebar with three sections: "Models", "Aspects", and "Plugins". The "Models" section has a "Create" tab and a "Navigate" tab, with a "Show Only My Models" checkbox checked. It lists three models: "Add Contingency", "Add System Contingency", and "Antenna Analysis", all associated with the user "khogstro". The "Aspects" section has a search bar and lists five aspects: "Acceleration Specified Maneuver", "Accelerometer", "ACS Drive Electronics", "ACS Maneuver - Impulse Specified", and "ACS Maneuver - Propellant Specifi...", all with a "+" icon. The "Plugins" section has a search bar and lists three plugins: "Design Extractor", "Hardware Picker", and "MEL plugin", all associated with the user "jcamacho". A pink banner in the bottom left corner reads "Prerelease b30". The footer text states "© 2019 California Institute of Technology. Government sponsorship acknowledged."

Demo - IME Workspace

all studies

root

Create Navigate

Models

+ Create New Model

☒ Show Only My Models

Search Models

Add Contingency + ✎ ✕
khogstro

Add System Contingency + ✎ ✕
khogstro

Antenna Analysis + ✎ ✕
khogstro

Aspects

Search Aspects

Acceleration Specified Maneuver +
Accelerometer +
ACS Drive Electronics +
ACS Maneuver - Impulse Specified +
ACS Maneuver - Propellant Specifi... +

Plugins

+ Create New Plugin

Search Plugins

Design Extractor ✎ ✕
jcamacho

Hardware Picker ✎ ✕
jcamacho

MEL plugin ✎ ✕
patrick kage

Prerelease b30

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Create models
with Python or
SpreadJS and
visualize with
HTML

Demo - IME Workspace

https://diecast.jpl.nasa.gov/app.html?studyId=study_513508805493&workspace=LeO7zsKMPJzivB0h

Demo

all studies

root / Flight Element / Propulsion Subsystem / Propulsion System

Biprop Engine

Parameters

- Thing with Name
 - Comment
 - Description
 - Name
- Thing with States
 - State Data
 - States 0 items... items...
- Dry Mass and Contingency
 - Mass Dry CBE 0 kg 0 kg
 - Mass Dry Contingency 0 0
 - Fraction
 - Mass Dry MEV 0 kg 0 kg
- Power Consumer
 - Power Consumed CBE 0 items... items...
- Rocket Engine
 - Isp 0 s 0 s
 - Thrust 0 N 0 N
- Biprop Engine
 - Fuel Type
 - Mixture Ratio 0 0
 - Oxidizer Type

Children

Models

+ Create New Model

☒ Show Only My Models

Search Models

- Add Contingency khogstro + ✎ ✕
- Add System Contingency khogstro + ✎ ✕
- Antenna Analysis khogstro + ✎ ✕

Aspects

biprop

- Biprop Engine +
- Biprop Engine - Detail +

Plugins

+ Create New Plugin

Search Plugins

- Design Extractor jcamacho ✎ ✕
- Hardware Picker jcamacho ✎ ✕
- MEL plugin patrick kage ✎ ✕

Prerelease b30

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Create models
with Python or
SpreadJS and
visualize with
HTML

Demo - IME Workspace x Rocket Equation from Final - IME x +

https://diecast.jpl.nasa.gov/app.html?studyId=study_513508805493&workspace=LeO7zsKMPJzivB0h

Demo

all studies

root / Flight Element / Propulsion Subsystem / Propulsion System

Biprop Engine

- Parameters
 - Thing with Name
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 - States 0 items... items...
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 - Mass Dry MEV 0 kg 0 kg
 - Power Consumer
 - Power Consumed CBE 0 items... items...
 - Rocket Engine
 - Isp 0 s 0 s
 - Thrust 0 N 0 N
 - Biprop Engine
 - Fuel Type
 - Mixture Ratio 0 0
 - Oxidizer Type
 - Children

Rocket Equation from Fir

0.297ms

- Inputs
 - Final Mass 0 kg 1000 kg
 - Delta V 0 m/s 450 m/s
 - Specific Impulse 0 s 300 s
- Outputs
 - Propellant Mass 165.275 kg 165.275 kg
- HTML Template

Models

+ Create New Model

☒ Show Only My Models

rocket e

Rocket Equation - Initial Mas... + ✎ ✕
khogstro

Rocket Equation from Final + ✎ ✕
khogstro

Aspects

biprop

Biprop Engine +

Biprop Engine - Detail +

Plugins

+ Create New Plugin

Search Plugins

Design Extractor ✎ ✕ ✕
jcamacho

Hardware Picker ✎ ✕ ✕
jcamacho

MEL plugin ✎ ✕ ✕
patrick kage

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Prerelease b30

Link blocks
together with
intuitive path
language and
dynamic search
results

Demo - IME Workspace x Rocket Equation from Final - IME x +

https://diecast.jpl.nasa.gov/app.html?studyId=study_513508805493&workspace=LeO7zsKMPJzivB0h

Demo all studies

root / Flight Element / Propulsion Subsystem / Propulsion System

Comment
Description
Name

Thing with States
State Data
States 0 items... items...

Dry Mass and Contingency
Mass Dry CBE 0 kg 0 kg
Mass Dry Contingency 0 0
Fraction
Mass Dry MEV 0 kg 0 kg

Power Consumer
Power Consumed CBE 0 items... items...

Rocket Engine
Isp 0 s 0 s
Thrust 0 N 0 N

Biprop Engine
Fuel Type
Mixture Ratio 0 0
Oxidizer Type

Children

Delta V 0 m/s 450 m/s
Specific Impulse 0 s 300 s
Outputs
Propellant Mass 165.275 kg 165.275 kg
HTML Template

Plot Rocket - KH

Inputs
Delta Vmin 0 m/s 0 m/s
Delta Vmax 1000 m/s 1000 m/s
Final Mass 100 kg 100 kg
Specific Impulse 300 s 300 s
HTML Template

Rocket Equation

Propellant Mass [kg]

Delta V [m/s]

Delta V: 530 m/s
Propellant Mass: 19.73967967 kg

CanvasJS.com

Pre-release b30

Create Navigate

Models
+ Create New Model
☒ Show Only My Models
plot ro
Plot Rocket - KH +
khogstro

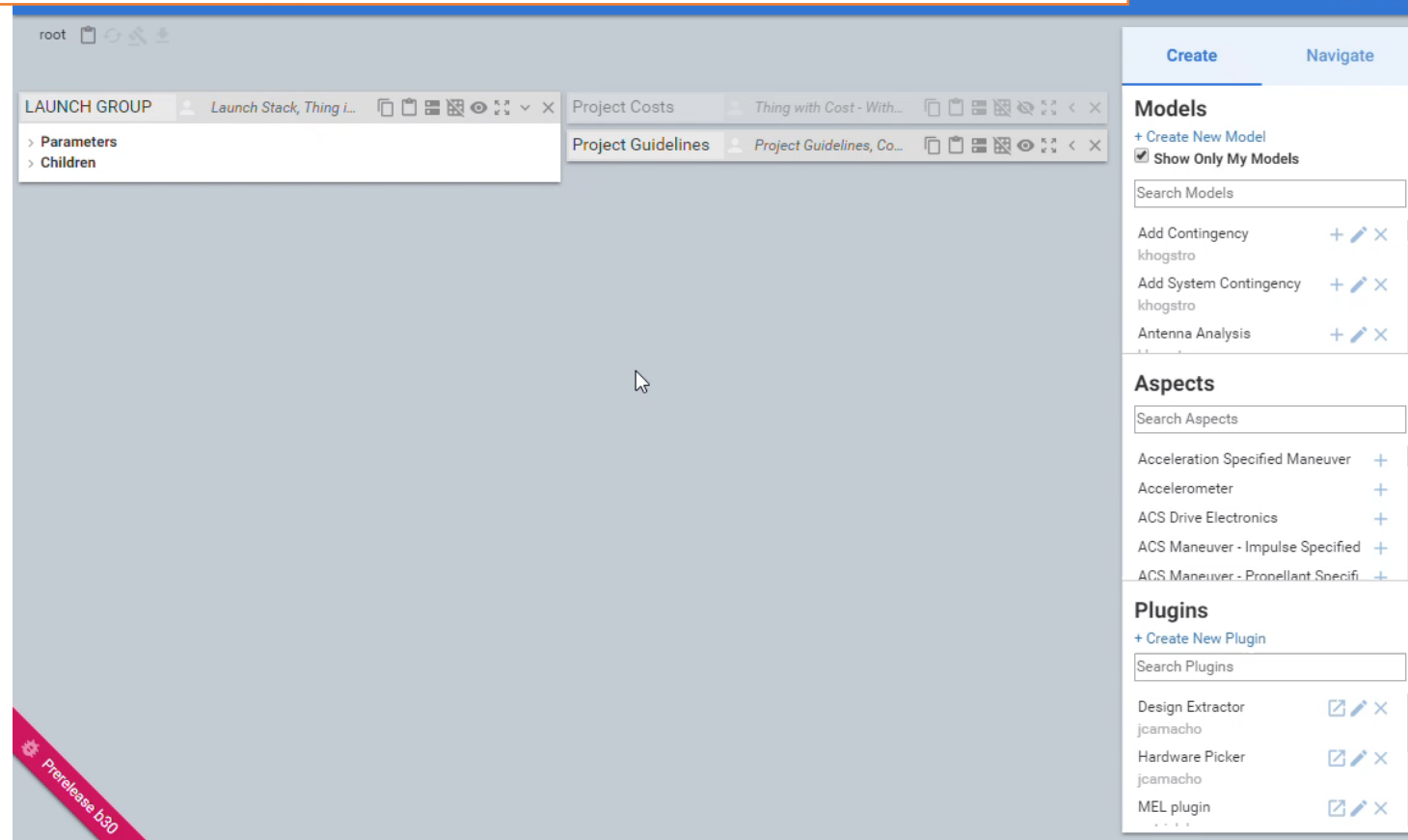
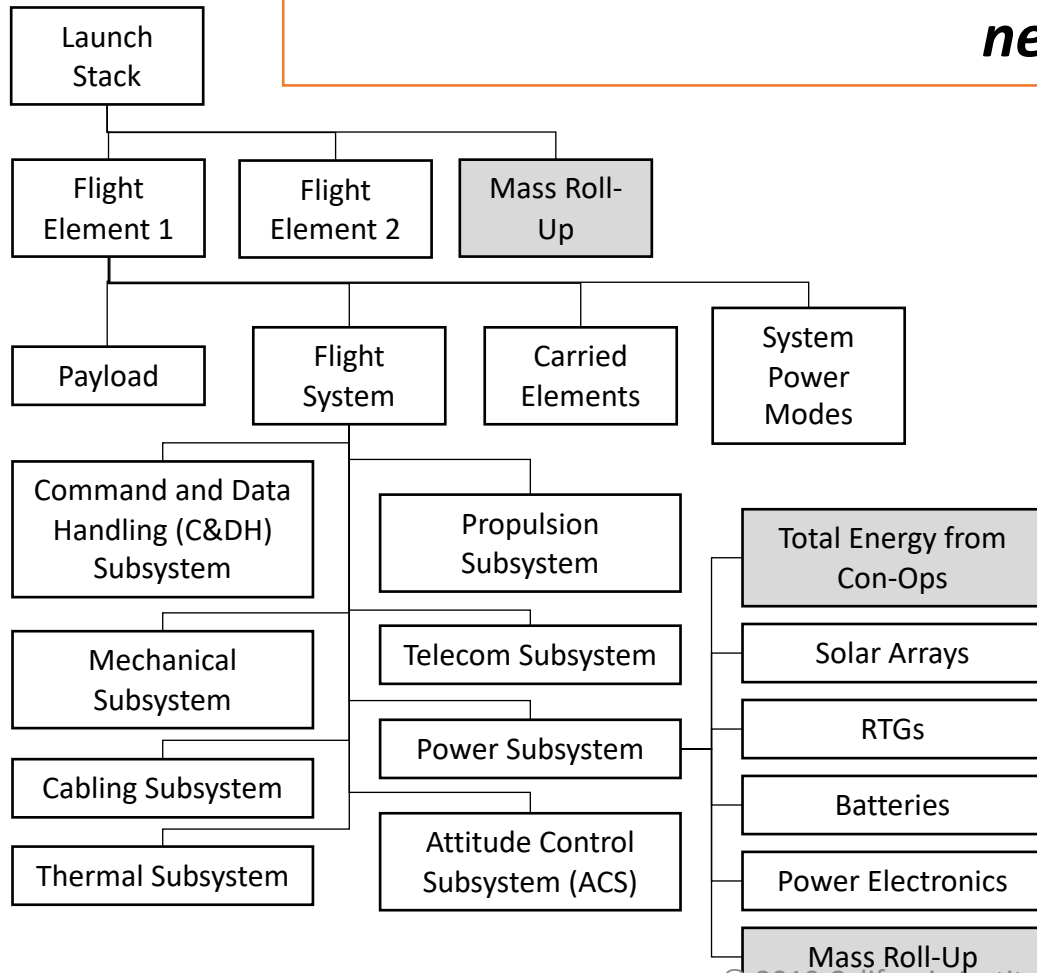
Aspects
biprop
Biprop Engine +
Biprop Engine - Detail +

Plugins
+ Create New Plugin
Search Plugins
Design Extractor jcamacho
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MEL plugin patrick kage



TATER Tree Structure

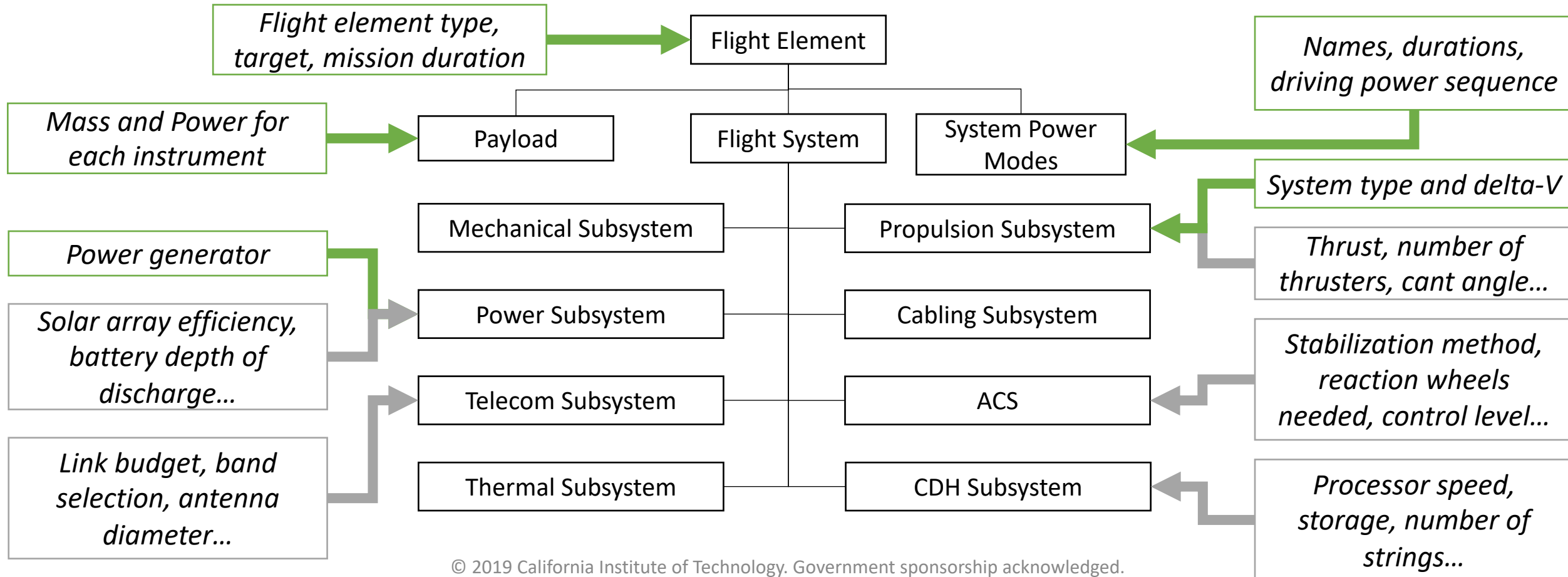
Model tree follows typical spacecraft architecture hierarchy, created by nesting blocks in IME





TATER Inputs

User starts with a pre-configured template that includes a default value for every flight system input. Results increase in accuracy and fidelity with better inputs.

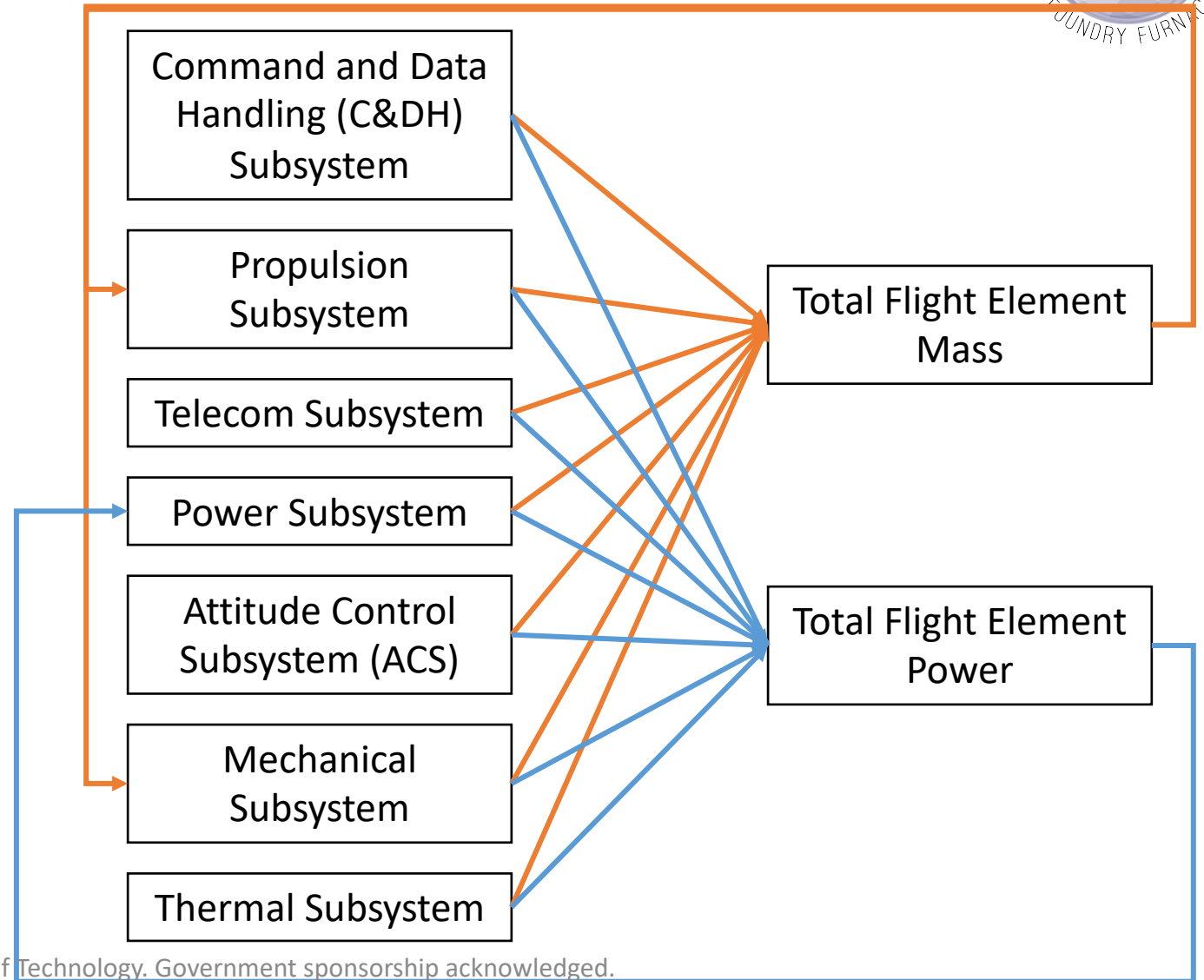


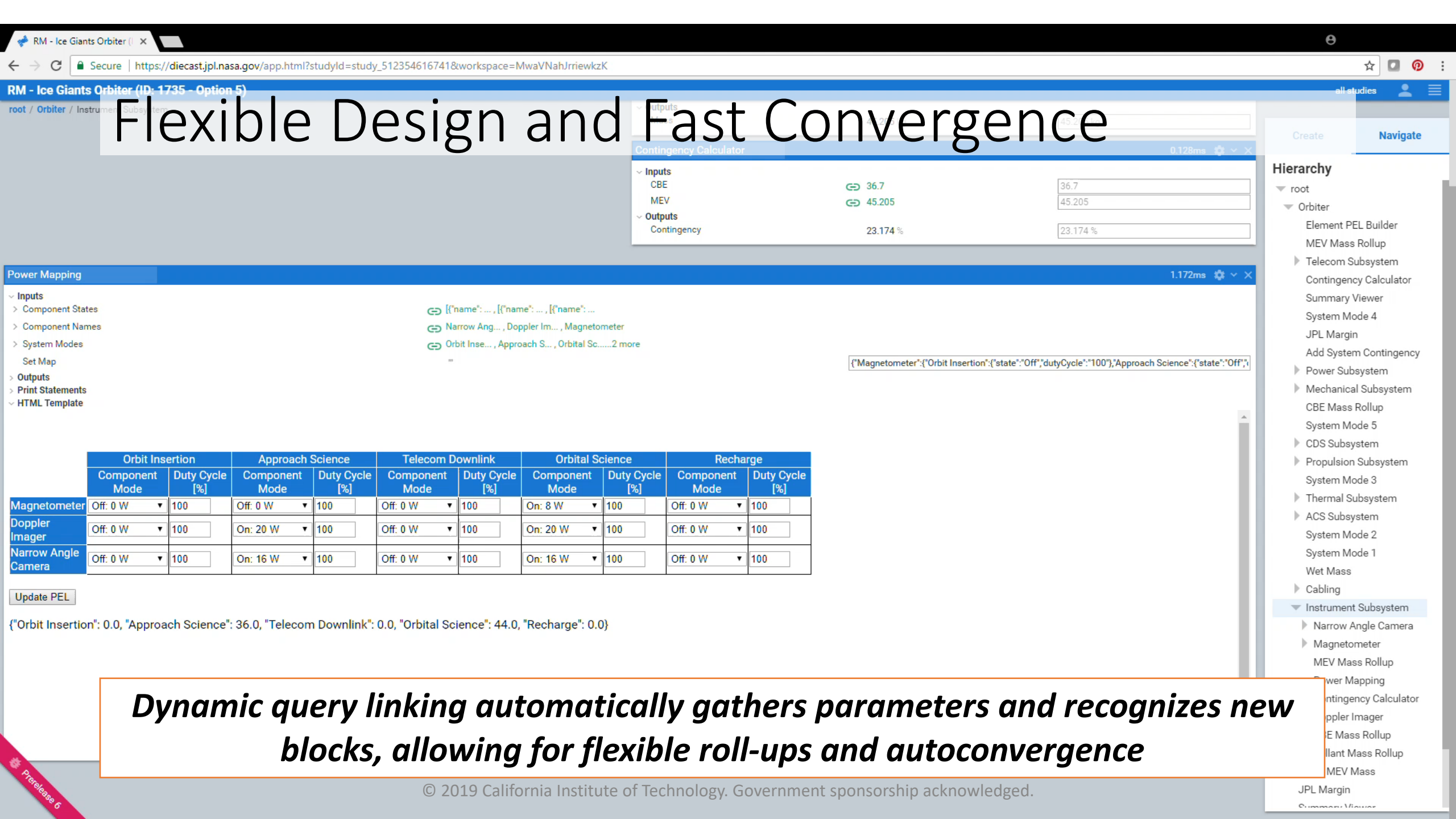
Self-Consistent Designs

— Mass link
— Power link



Through an intricate web of linked models and data blocks, TATER captures subsystem dependencies and produces self-consistent and converged designs





Flexible Design and Fast Convergence

| Contingency Calculator | | | |
|------------------------|----------|----------|--|
| 0.128ms | | | |
| Inputs | | | |
| CBE | 36.7 | 36.7 | |
| MEV | 45.205 | 45.205 | |
| Outputs | | | |
| Contingency | 23.174 % | 23.174 % | |

Power Mapping

- Inputs
 - Component States
 - Component Names
 - System Modes
 - Set Map
 - Outputs
 - Print Statements
 - HTML Template
- ["name": "...", [{"name": "...", [{"name": "...
- Narrow Ang..., Doppler Im..., Magnetometer
- Orbit Inse..., Approach S..., Orbital Sc.....2 more

| | Orbit Insertion | | Approach Science | | Telecom Downlink | | Orbital Science | | Recharge | |
|---------------------|-----------------|----------------|------------------|----------------|------------------|----------------|-----------------|----------------|----------------|----------------|
| | Component Mode | Duty Cycle [%] | Component Mode | Duty Cycle [%] | Component Mode | Duty Cycle [%] | Component Mode | Duty Cycle [%] | Component Mode | Duty Cycle [%] |
| Magnetometer | Off: 0 W | 100 | Off: 0 W | 100 | Off: 0 W | 100 | On: 8 W | 100 | Off: 0 W | 100 |
| Doppler Imager | Off: 0 W | 100 | On: 20 W | 100 | Off: 0 W | 100 | On: 20 W | 100 | Off: 0 W | 100 |
| Narrow Angle Camera | Off: 0 W | 100 | On: 16 W | 100 | Off: 0 W | 100 | On: 16 W | 100 | Off: 0 W | 100 |

Update PEL

{"Orbit Insertion": 0.0, "Approach Science": 36.0, "Telecom Downlink": 0.0, "Orbital Science": 44.0, "Recharge": 0.0}

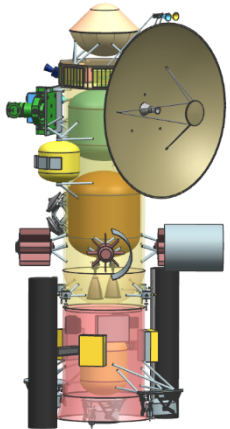
Hierarchy

- root
 - Orbiter
 - Element PEL Builder
 - MEV Mass Rollup
 - Telecom Subsystem
 - Contingency Calculator
 - Summary Viewer
 - System Mode 4
 - JPL Margin
 - Add System Contingency
 - Power Subsystem
 - Mechanical Subsystem
 - CBE Mass Rollup
 - System Mode 5
 - CDS Subsystem
 - Propulsion Subsystem
 - System Mode 3
 - Thermal Subsystem
 - ACS Subsystem
 - System Mode 2
 - System Mode 1
 - Wet Mass
 - Cabling
 - Instrument Subsystem
 - Narrow Angle Camera
 - Magnetometer
 - MEV Mass Rollup
 - Power Mapping
 - Contingency Calculator
 - Doppler Imager
 - CBE Mass Rollup
 - Orbital Mass Rollup
 - MEV Mass
 - JPL Margin
 - Summary Viewer

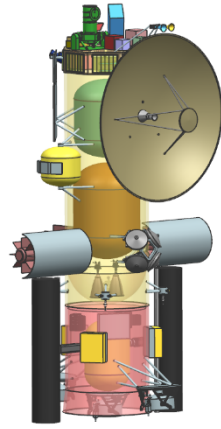
Dynamic query linking automatically gathers parameters and recognizes new blocks, allowing for flexible roll-ups and autoconvergence

Verification and Validation

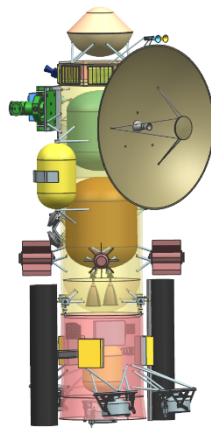
Compared Team X and TATER subsystem masses for the six options studied in the 2017 Ice Giants pre-Decadal report



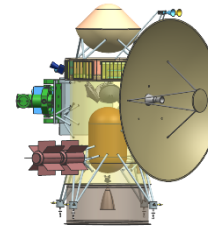
Option 1:
Uranus orbiter
SEP stage
Probe



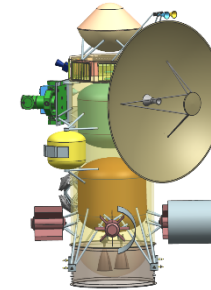
Option 2:
Uranus orbiter
SEP stage
No probe



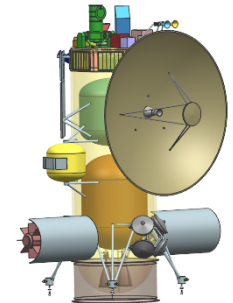
Option 3:
Neptune orbiter
SEP stage
Probe



Option 4:
Uranus fly-by
All chemical
Probe



Option 5:
Uranus orbiter
All chemical
Probe



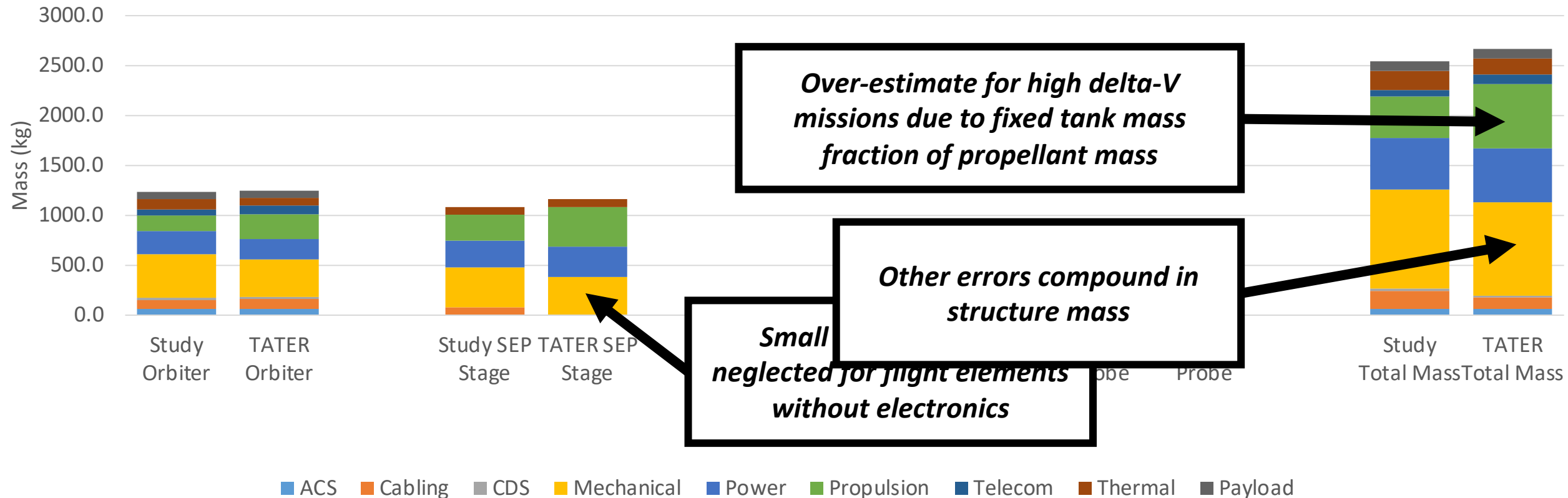
Option 6:
Uranus orbiter
All chemical
No probe



Verification and Validation

TATER matched the Ice Giants study results to within 14% at the flight element level

Summary of Options





Conclusions and Future Work

TATER is ready for application to mission studies in A-Team

Model Improvement

- Resolve discrepancies identified in initial validation exercise
- Repeat validation
- Increase validation scope to include power, cost, and wider range of architectures
- Add capabilities and models for selected subsystems and new technologies

Software Improvement

- Explore multiple architecture options and perform Monte Carlo trades
- Time-dependent sequences and states for con-ops



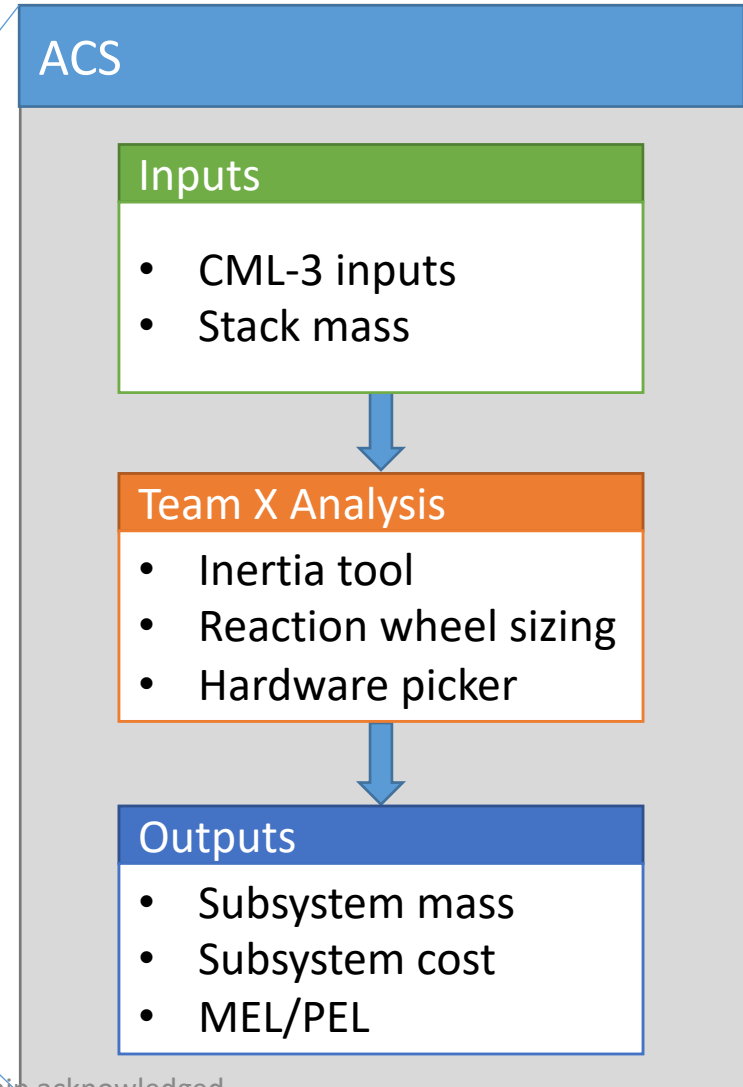
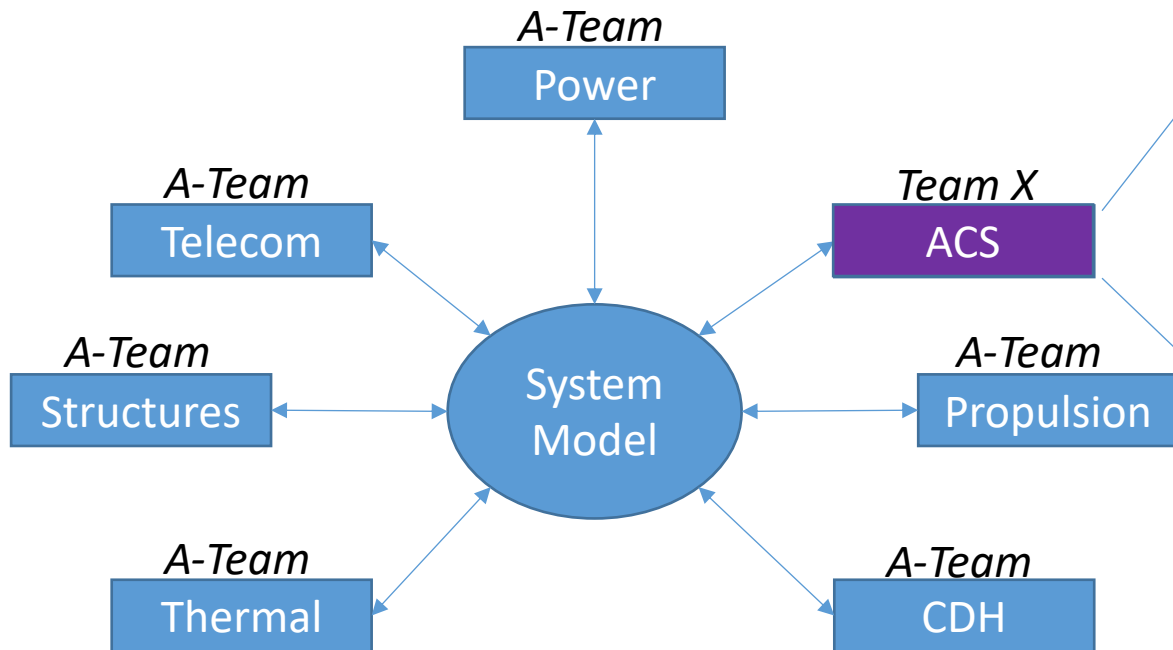
TATER Beyond the A-Team

Common system-level architecture across the Foundry

Drag-and-drop replacement of models

Do deep dives and increase fidelity

Side-by-side comparison of versions



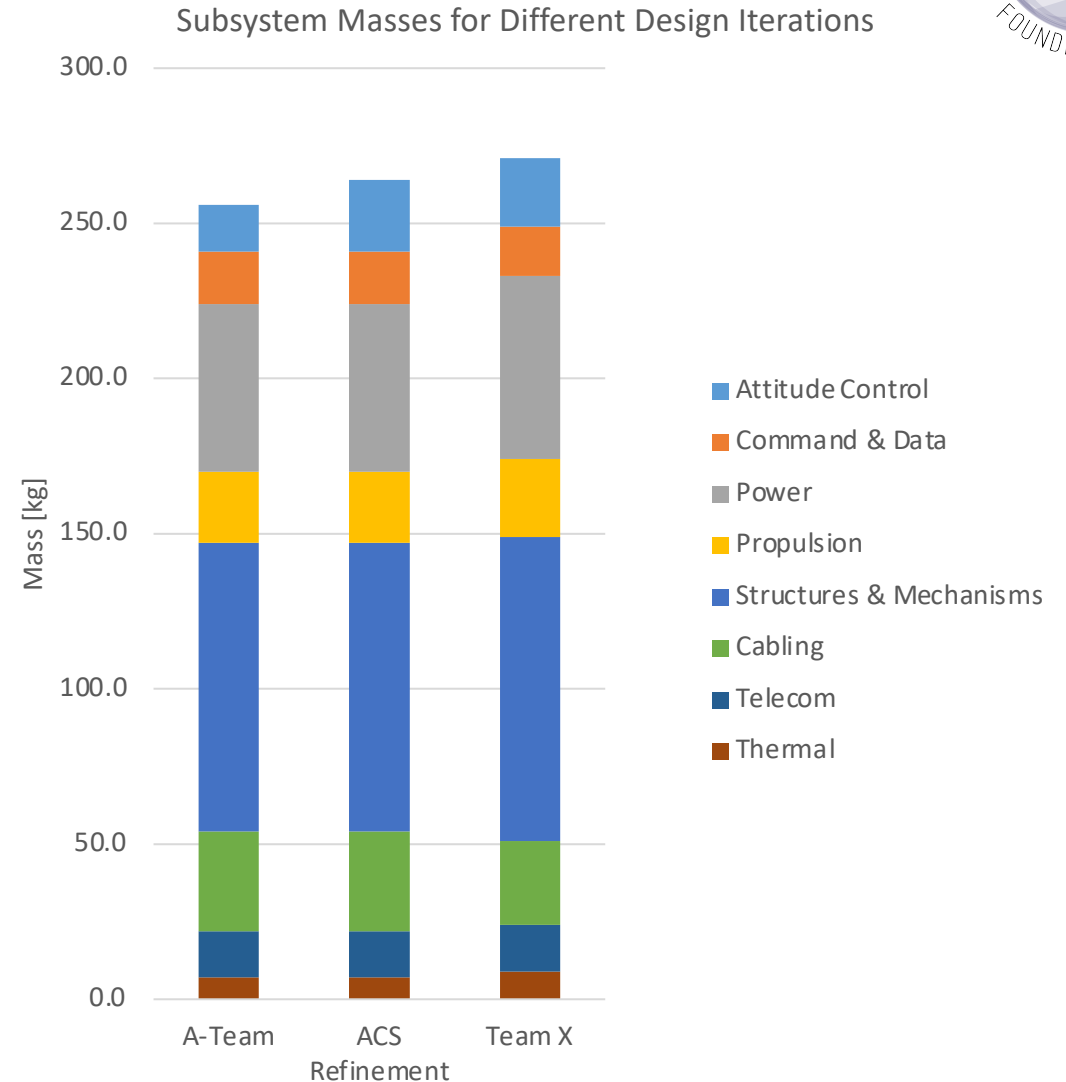
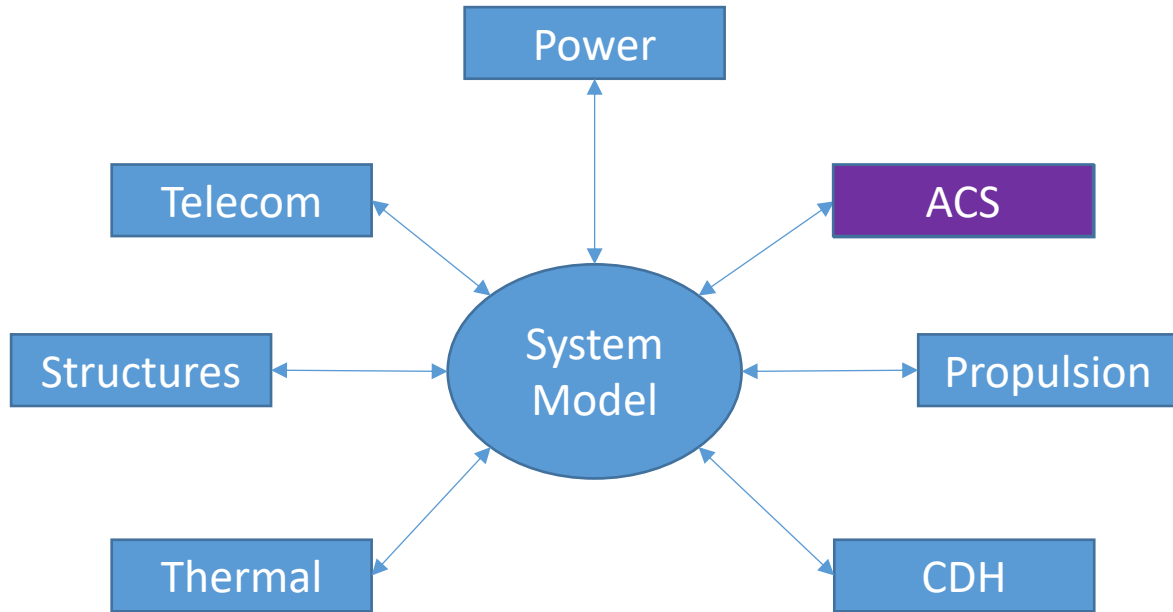
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Acknowledgements

- JPL Innovation Foundry
- Foundry Modernization team
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